

times and for confining airplanes as closely as possible to areas to be surveyed.

The idea underlying the design is that if the antenna can be kept properly aimed, then the incidence of cycle slips caused by loss or weakness of signals can be minimized. The system includes an articulating GPS antenna and associated electronic circuitry mounted under a radome atop an airplane. The electronic circuitry includes a microprocessor-based interface-circuit-and-data-translation module. The system receives data on the current attitude of the airplane from the

inertial navigation system of the airplane. The microprocessor decodes the attitude data and uses them to compute commands for the GPS-antenna-articulating mechanism to tilt the antenna, relative to the airplane, in opposition to the roll or bank of the airplane to keep the antenna pointed toward the zenith.

The system was tested aboard the hurricane-hunting airplane of the National Oceanic and Atmospheric Administration (NOAA) [see figure] during an 11-hour flight to observe the landfall of Hurricane Bret in late summer of 1999. No bank-

angle restrictions were imposed during the flight. Post-flight analysis of the GPS trajectory data revealed that no cycle slip had occurred.

This work was done by C. Wayne Wright of Goddard Space Flight Center. Further information is contained in a TSP (see page 1).

This invention has been patented by NASA (U.S. Patent No. 6,844,856 B1). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center, (301) 286-7351. Refer to GSC-14436-1

Improved Starting Materials for Back-Illuminated Imagers

Thin, highly doped layers are no longer degraded by high-temperature annealing.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved type of starting materials for the fabrication of silicon-based imaging integrated circuits that include back-illuminated photodetectors has been conceived, and a process for making these starting materials is undergoing development. These materials are intended to enable reductions in dark currents and increases in quantum efficiencies, relative to those of comparable imagers made from prior silicon-on-insulator (SOI) starting materials.

Some background information is prerequisite to a meaningful description of the improved starting materials and process. A prior SOI starting material, depicted in the upper part the figure, includes:

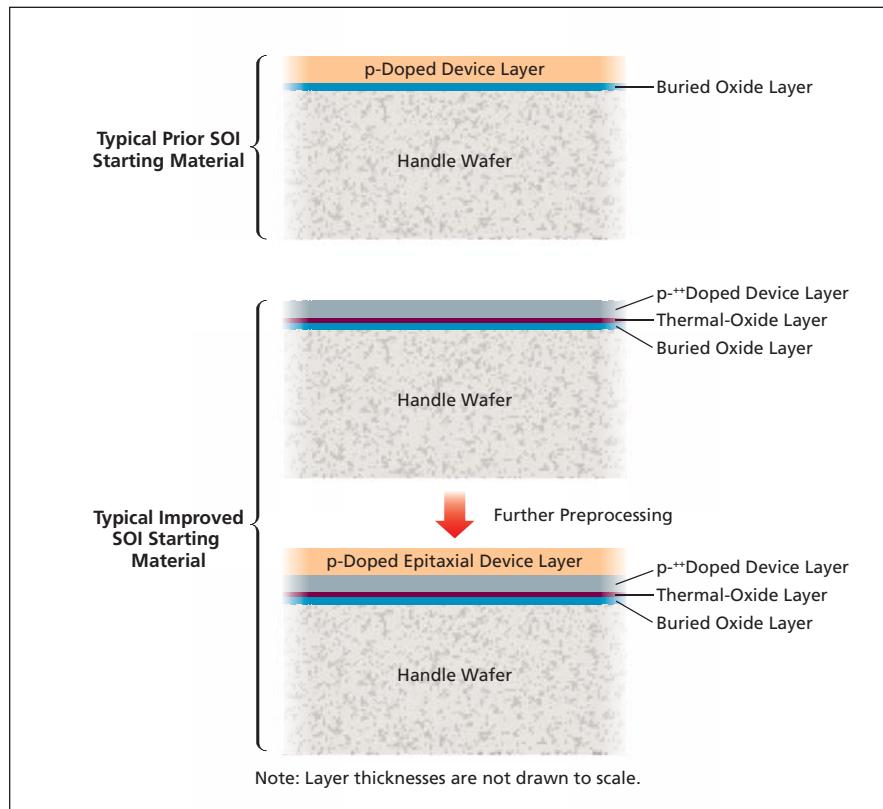
- A device layer on the front side, typically between 2 and 20 μm thick, made of p-doped silicon (that is, silicon lightly doped with an electron acceptor, which is typically boron);
- A buried oxide (BOX) layer (that is, a buried layer of oxidized silicon) between 0.2 and 0.5 μm thick; and
- A silicon handle layer (also known as a handle wafer) on the back side, between about 600 and 650 μm thick.

After fabrication of the imager circuitry in and on the device layer, the handle wafer is etched away, the BOX layer acting as an etch stop. In subsequent operation of the imager, light enters from the back, through the BOX layer. The advantages of back illumination over front illumination have been discussed in prior *NASA Tech Briefs* articles.

For reasons too complex to discuss within the space available for this article,

one modification that is necessary for reducing dark current and increasing quantum efficiency is the incorporation of a thin, heavily doped (e.g., p^{++} -doped with boron) silicon layer between the lightly doped device layer and the BOX layer. In prior research, an attempt to incorporate a thin, heavily doped layer by implanting boron at the BOX/device-silicon interface before

bonding the BOX layer to the handle wafer did not yield the desired doping profile: The bonding process unavoidably included a high-temperature anneal that caused the implanted boron to diffuse away from the interface, thereby causing an undesired decrease in the doping concentration at the interface and an undesired increase in the doping concentration in the device layer.



An **SOI Starting Material** of the present improved type differs from a typical prior SOI starting material in several respects.

This concludes the background information.

A starting material of the present improved type, depicted in the middle and lower parts of figure, differs from prior SOI starting materials in the following ways:

- The front silicon layer is heavily doped [e.g., p⁺⁺-doped with boron], typically at a concentration of 10^{19} atoms/cm³ instead of being lightly doped at the conventional device concentration of 10^{15} atoms/cm³.
- There is a layer of thermal oxide between the front silicon layer and the BOX layer.
- The starting material is further pre-processed by growing, to an appropriate thickness, a front epitaxial silicon layer that is lightly doped (e.g., p-doped) typically at a concentration of

7×10^{14} boron atoms/cm³. This front epitaxial layer serves as the device layer in subsequent fabrication of an imager.

The advantage afforded by such an improved starting material arises from the fact that epitaxial silicon is grown at a temperature much lower than that of the anneal in the aforementioned BOX-to-handle-wafer-bonding process. Therefore, diffusion of boron away from the interface and into the device silicon is prevented. Optionally, one could perform an anneal at an intermediate temperature chosen to effect a small amount of diffusion to optimize the doping profile. Furthermore, the performance of the imager circuitry can be improved because the quality of the epitaxial silicon in the improved starting material is better than that of the float-

zone device-layer silicon in prior SOI starting materials. All of the arguments made above would remain valid for cases in which electron-donor (n) dopants were substituted for p dopants.

This work was done by Bedabrata Pain of Caltech for NASA's Jet Propulsion Laboratory. In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-41233, volume and number of this NASA Tech Briefs issue, and the page number.

Multi-Modulator for Bandwidth-Efficient Communication

Coding and modulation can be selected by loading configuration bits into an FPGA.

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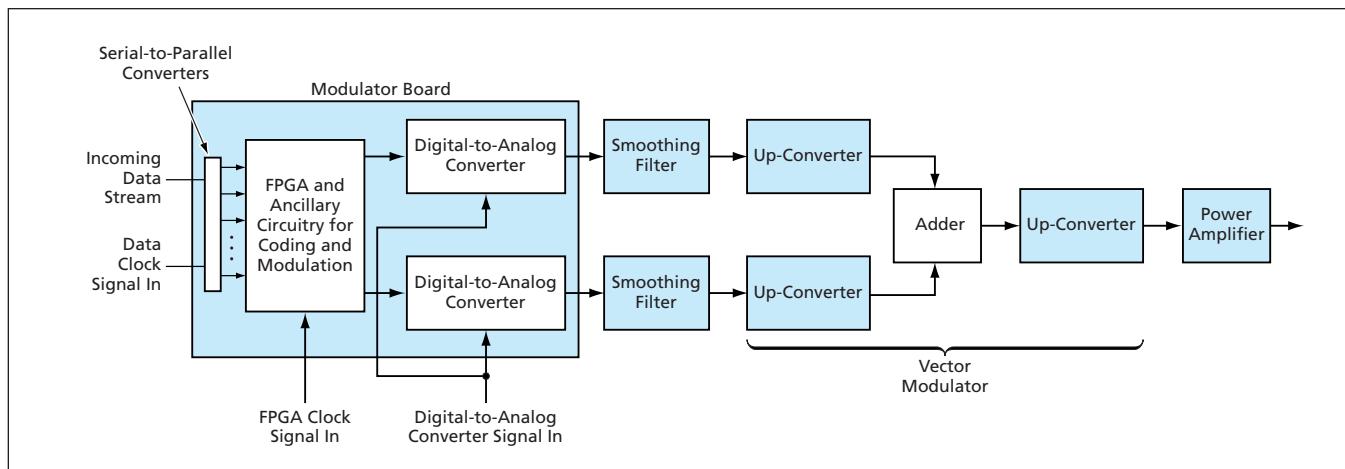
A modulator circuit board has recently been developed to be used in conjunction with a vector modulator to generate any of a large number of modulations for bandwidth-efficient radio transmission of digital data signals at rates that can exceed 100 Mb/s. The modulations include quadrature phase-shift keying (QPSK), offset quadrature phase-shift keying (OQPSK), Gaussian minimum-shift keying (GMSK), and octotary phase-shift keying (8PSK) with square-root raised-cosine pulse shaping. The figure is a greatly simplified block diagram showing the relationship

between the modulator board and the rest of the transmitter. The role of the modulator board is to encode the incoming data stream and to shape the resulting pulses, which are fed as inputs to the vector modulator. The combination of encoding and pulse shaping in a given application is chosen to maximize the bandwidth efficiency.

The modulator board includes gallium arsenide serial-to-parallel converters at its input end. A complementary metal oxide/semiconductor (CMOS) field-programmable gate array (FPGA) performs the coding and modulation

computations and utilizes parallel processing in doing so. The results of the parallel computation are combined and converted to pulse waveforms by use of gallium arsenide parallel-to-serial converters integrated with digital-to-analog converters. Without changing the hardware, one can configure the modulator to produce any of the designed combinations of coding and modulation by loading the appropriate bit configuration file into the FPGA.

At the time of reporting the information for this article, a prototype of the modulator board had been tested in lab-



The Modulator Board is part of a radio transmitter, wherein it processes an incoming data stream in such a way as to generate modulator inputs for bandwidth-efficient modulation.